Flight Tunnel and Field Evaluations of Sticky Traps for Monitoring Codling Moth (Lepidoptera: Tortricidae) in Sex Pheromone-treated Orchards

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ABSTRACT

Delta, diamond, and wing style sticky traps baited with codlemone were evaluated in both flight tunnel and in field trials to determine their performance in capturing male codling moth *Cydia pomonella* (L.). Flight tunnel studies found no differences among trap types in terms of moth orientation behaviors. However, the proportion of moths contacting each trap type that were caught varied significantly. The 1CP wing trap caught a lower proportion of moths than the IIB diamond trap due to a significantly lower efficiency in retaining moths that landed on the trap. The position of a moth's first contact varied among traps with a significantly higher proportion landing on the outside of the wing style versus the delta and diamond traps. A significantly lower proportion of moths first landing on the outside of the delta trap were caught than for moths landing on the outside of the 1C wing trap. A significantly lower proportion of moths landing on the front opening of the 1CP wing trap were captured than for the other traps. No differences were found among trap types for either the proportion of moths flying into traps or the proportion of these moths captured. A majority of moths orienting to the diamond and delta traps first landed on the front flap and walked into the trap. The removal of the front flap from these traps did not affect their efficiency. However, a significantly greater proportion of moths flew directly into the delta trap when the flap was removed. Lure position within a delta trap did not affect moth catch, but it did affect the position of a moth's first contact with the trap. Lures placed high in the trap elicited moth landing on the inside surface of the trap's side or on the outside of the trap. Moths tended to land on the front flap when lures were placed in the adhesive. The relative field performance of traps in a sex pheromone-treated apple orchard was consistent with the flight tunnel studies, however, it was also influenced by moth population density. The 1CP trap caught significantly fewer moths than the other traps in an orchard with low codling moth density. The mean cumulative moth catch of each trap type was proportional to its adhesive-treated surface area within orchards receiving releases of sterile moths.

Key words: codling moth, traps, monitoring, mating disruption, sex pheromones

INTRODUCTION

Traps baited with codlemone, the major sex pheromone component of codling moth, *Cydia pomonella* L. (Roelofs *et al.* 1971), have been used for > 25 yr to monitor populations in tree fruit orchards (Butt *et al.* 1974, Maitlen *et al.* 1976). Cumulative male catches in traps have been used to establish action thresholds for insecticide usage (Madsen and Vakenti 1972, Madsen *et al.* 1974, Riedl and Croft 1974) and as an indicator of phenology (Riedl *et al.* 1976, Beers and Brunner 1992). Moth catch has also been used to evaluate the success of mating disruption in orchards treated with sex pheromone (Vickers and Rothschild 1991).

The efficacy of a variety of trap types has been evaluated for codling moth in field trials (earlier work summarized in Riedl *et al.* 1986, Knodel and Agnello 1990, Vincent *et al.* 1990, Kehat *et al.* 1994). Traps have typically been constructed with inexpensive and disposable cardboard or plastic materials and have had a variety of shapes including cylindrical, delta, diamond and wing-style. Both disposable, sticky and reusable, non-sticky trap designs have been tested and compared (Knodel and Agnello 1990, Vincent *et al.* 1990). A synthesis of this work led to the suggestion and partial implementation of a standard protocol for monitoring codling moth with traps and lures (Riedl *et al.* 1986). The use of a wing trap with a notched bottom liner (Pherocon 1CP) baited with a red rubber septum loaded with 1.0 mg codlemone has been the mostly widely used monitoring system in the western U.S. during the 1980's and 1990's (Riedl *et al.* 1986, Gut and Brunner 1998).

The adoption of sex pheromone dispensers for mating disruption of codling moth occurred relatively rapidly during the 1990's in apple and pear orchards of Washington, California, and British Columbia, Canada. A prerequisite for the adoption of this new technology was the need to develop more intensive monitoring programs. Recommendations for monitoring included the use of a higher density of traps to detect potential problem areas within orchards and baiting traps with lures containing higher loads of pheromone to minimize the occurrence of "false negatives" in moth counts (Gut and Brunner 1996). The increased importance of monitoring in sex pheromone-treated orchards also led to the use of new trap designs including a larger delta trap and a new diamond-shaped trap. Unfortunately, the variability in the physical characteristics of these traps has hindered the implementation of a standardized protocol for monitoring codling moth and has created uncertainty among pest managers interpreting moth catches (Knight and Christianson 1999). To date, a comparison of these traps' performances for codling moth has not been reported.

Optimizing trap design is vital in developing a useful monitoring system. Slight changes in trap design can modify the pheromone plume structure and strongly affect moth flight and landing responses to a trap (Lewis and Macaulay 1976). Typically for most pest species, trap designs have been compared in a non-systematic, *ad hoc* approach without regard to understanding the effect of their individual features on moth behavior (Phillips and Wyatt 1992). Conversely, controlled studies of moth behavior in flight tunnels have proven to be useful in improving trap designs (Foster and Muggleston 1993, Foster *et al.* 1995). A study of codling moth's response to traps under controlled conditions in a flight tunnel has not been reported. Here we compare codling moth's behavioral response to four trap designs. In addition, the field performances of these traps were compared under low and high moth densities in trials conducted within apple orchards treated with sex pheromone dispensers for mating disruption.

MATERIALS AND METHODS

Trap types. Studies were conducted with several paper and plastic trap types manufactured by Trécé Inc. (Salinas, CA) that are commonly used in tree fruits in the western United States: the delta trap, Pherocon VI; the diamond trap, Pherocon IIB; and the wing style traps, Pherocon 1C and Pherocon 1CP. The four traps vary in their overall geometries but have similar exterior dimensions, except for the smaller IIB diamond trap (Table 1). The two wing traps differ with regard to their bottom piece. The two pieces of the 1C wing trap are separated by a 5 cm plastic spacer and are the same size. The bottom wing in the 1CP wing trap is smaller and fits underneath the upper wing. The primary opening of the 1CP wing trap is a 4.0 x 5.6 cm notch cut in the center edge of the bottom piece. The area of the four traps' interior surfaces coated with adhesive was not related to a trap's exterior dimensions. The smaller IIB diamond trap has the largest area coated with adhesive; however, only 50% of this treated surface is situated on the bottom of the trap. The 1C wing trap has the largest horizontal adhesive-treated surface area and the 1CP wing trap has the smallest surface area. Interestingly, the percentage of the horizontal surface that is effectively covered with adhesive varied among traps. The bottom surface of the IIB diamond trap is the only trap completely covered with adhesive. The other three traps have 23 - 48% of their inside bottom surface left untreated (Table 1). The ratio of nonsticky to sticky surfaces varies among traps, primarily due to the variability in the exterior size of the traps and because all three inside surfaces of the IIB diamond trap are treated with adhesive. Both the VI delta and the IIB diamond traps have front flaps (flap height is about 3.0 cm) that are not treated with adhesive. The area and maximum height of three of the trap's openings are similar. However, the opening of the 1CP wing trap is only half as large as the other traps (Table 1).

Table 1.

Physical characteristics of the Pherocon traps (Trécé Inc., Salinas, CA) evaluated in this study

	Trap type			
Trap characteristics	VI delta	IIB diamond	1C wing	1CP wing
Exterior dimensions (cm) length by width	27.0 x 20.0	17.8 x 16.5	26.0 x 22.0	26.0 x 22.0
Area (cm^2) of adhesive-covered bottom inside surface	420.0	248.7 (497.4) [a]	409.4	227.3
% inside trap bottom covered with adhesive	87.3	100.0	64.1	51.7
Ratio of non-sticky to sticky trap surfaces	6.9	1.7	5.2	8.5
Height (cm) of front flap	3.3	1.5 – 3.0	-	-
Area (cm^2) of trap opening	42.8 (8.0)[b]	48.0 (7.0)	42.7 (5.0)	26.5 (2.5)

[a] Value in parentheses is the area of all interior surfaces covered with adhesive.
[b] Value in parentheses is the maximum height of the trap's opening (cm).

Flight Tunnel Studies. The flight tunnel was constructed from 6 mm acrylic sheeting (1.66 m long, 0.57 m wide and 0.57 m high). A 12-volt DC blower was used to pull air from the room (maintained at 22-24 °C and 50-60% RH) into a plenum, through a charcoal filter, and through a series of screens before passing into the tunnel. Air flow through the tunnel was maintained at 0.25 m/sec. Exhaust was expelled to the outside of the building. Red lights installed above the tunnel provided enough light (4.3 lux) to make behavioral observations. Traps were placed on a ring stand 0.31 m above the tunnel floor and 0.20 m from the entrance of the tunnel. Traps were baited with a halobutyl gray septum loaded with 0.1 mg codlemone. Lures were pinned to the middle of the trap bottom and above the adhesive in all traps, except in the study that evaluated the effect of lure position.

Male moths (< 36 h old) were obtained from the USDA laboratory colony reared on artificial diet, and conditioned in constant light for 24 - 48 h at 21 °C and 60% RH. Prior to testing, moths were placed in complete darkness for 30 min then released from a 30 cm high platform placed near the air outlet end of the tunnel. Individual moths were flown to traps and moth behavior was recorded for 6 min or until the moth was caught in the trap. New traps were used after each replicate.

The first study compared moth's responses to each trap type. Trap order was randomized on each day. Five moths (18 replicates) were flown consecutively to each trap type. The occurrence of wing fanning, upwind anemotactic flight, landing on the trap, entering the trap, and capture were recorded for each moth for the first six replicates. Data were also recorded for the position of first moth contact with the trap for the last 12 replicates. The location of first moth contact with the trap was summarized into three categories: landing on the outside of the trap, landing on the opening of the trap, or flying inside the trap. Moths landing on the front flaps of the IIB and VI traps were scored as landing on the front opening.

Two additional studies were conducted in the flight tunnel to evaluate specific features of the trap / lure system. The first test evaluated the response of males to both the IIB and the VI traps with and without front flaps. Flaps were removed with a razor blade. Forty moths were flown to each of these four trap types using the same experimental procedure (the order of traps was randomized each day and five moths were flown consecutively for 6 min to each trap). Eight replicates were run with each trap. The occurrences of wing fanning, upwind anemotactic flight, landing on the trap, entering the trap, capture, and the position of first contact on the trap were recorded for each moth. The second test evaluated the effect of lure position within the VI delta trap on capture efficiency. Three lure positions within the trap were compared: pinned to the top center, pinned to the bottom center, and pinned to the bottom side. The occurrences of wing fanning, upwind anemotactic flight, landing on the trap, entering the trap, capture, and the position of first contact on the trap were recorded for each moth. Forty moths were flown to traps with each lure position using the same experimental procedure described above.

Field trials. Two field tests were conducted to evaluate the performance of the four trap types in apple orchards treated with sex pheromone dispensers (1,000 Isomate C+ dispensers per ha, Pacific Biocontrol, Vancouver, WA). Fifteen traps of each of the four trap types were randomly spaced 20 m apart in an 18 ha 'Red Delicious' orchard near Moxee, WA in test 1. Trap height was standardized at 3.0 m in the canopy (mean (SE) tree height averaged 4.1 (0.1) m). The test was conducted from 17 April to 4 May 1998. Test 2 was conducted from 20 August to 9 September 1998 in a nearby 14 ha 'Red Delicious' orchard. Trap height was standardized at 3.0 m in the canopy (mean (SE) tree height averaged 4.2 (0.1) m). Ten replicates of each trap type were randomized within the orchard and spaced 20 m apart. Five thousand sterile codling moths (50:50 male: female ratio) obtained from the Sterile Insect Release Program (Osoyoos, British Columbia) were released into this orchard just prior to the start of the study and again on 27 August and 3 September. Sterilized moths were exposed to 33 krad of gamma radiation and stored at 2 °C for < 48 h prior to release. Moth catch in each trap was recorded every two days; however moths were not removed from traps during the test.

Data analysis. A multiple comparison test for proportions (Ryan 1960) was used to test for significant differences ($P = 0.05$) among trap types in the behavioral response of moths (orientation to the trap, trap contact, and moth capture) in the flight tunnel tests. Ryan's test was also used to test for differences among traps for the proportion of moths first contacting a given position on the trap (outside, front opening, and inside) and for each position's capture efficiency. Fisher's exact test (2 x 2 contingency table) was used to compare the proportion of moths captured in tests evaluating the delta and diamond traps with and without front flaps. Chi-square analysis was used to compare the frequency distribution of moth contact in delta traps with lures placed at three positions within traps. All moth counts in field trials were transformed with square root (x + 0.01) and tested with analysis of variance (PROC GLM, Hintze 1987). Means were separated in significant ANOVA's with Fisher's least significance difference (Hintze 1987).

RESULTS

Flight Tunnel Studies. No difference in the proportion of moths orienting to or touching the traps was found among traps (Table 2). However, the proportion of moths touching the 1CP wing trap that were caught was significantly lower than for the 1C wing and IIB diamond traps. The proportion of moths tested that were trapped was significantly lower with the 1CP wing versus the IIB diamond trap.

The distribution of moth contacts with traps and the proportion of moths captured varied among traps (Table 3). A significantly higher proportion of moths first contacted the wing traps on the outside of the traps versus the VI delta and IIB diamond traps. The proportion of moths landing on the outside of the VI delta trap that was eventually caught in the adhesive was significantly lower than with the 1C wing trap. A significantly lower proportion of moths contacting the wing traps landed on the opening of the trap versus the proportion landing on the flaps of the IIB diamond and VI delta traps. Capture efficiency for these moths was significantly lower for the 1CP than the other traps. No significant difference was found among traps for the proportion of moths that flew directly into the trap though nearly 3-fold more moths flew into the VI delta than the wing traps. The capture rate for moths flying into all four traps was > 72%. Moths entering the IIB diamond trap avoided the two adhesive-covered upper sides and were never caught on their surfaces.

Table 2.

Flight tunnel response of codling moth males to traps baited with a grey septa loaded with 0.1 mg codlemone, n = 30.

	Proportion of moths			
Trap type	Released that oriented to trap	Orienting that contacted trap	Contacting trap that were caught	Released that were caught
VI Delta	0.77a	1.00a	0.82ab	0.62ab
IIB Diamond	0.73a	1.00a	0.96a	0.70a
1C Wing	0.70a	0.95a	0.95a	0.63ab
1CP Wing	0.70a	0.90a	0.74b	0.47b

Column proportions are not significantly different if followed by the same letter, $P < 0.05$; Ryan's (1960) multiple comparison test for proportions.

Table 3.

Distribution of male codling moths' first contact with several trap types baited with 0.1 mg codlemone and the success of moth capture for each trap location in flight tunnel tests (n=6).

	Number of moths contacting	Proportion of moths first contacting[1]:					
		Outside of trap		Front opening of trap		Flying inside trap	
Trap type	trap	Landing	Captured	Landing	Captured	Landing	Captured
Pherocon VI Delta	50	0.10b	0.10b	0.56a	0.83a	0.34a	0.94a
Pherocon IIB Diamond	41	0.10b	0.25ab	0.63a	0.81a	0.27a	0.73a
Pherocon 1C Wing	34	0.56a	0.58a	0.32b	0.82a	0.12a	0.75a
Pherocon 1CP Wing	36	0.56a	0.30ab	0.31b	0.55b	0.14a	0.80a

Column proportions are not significantly different if followed by the same letter, $P < 0.05$; Ryan's (1960) multiple comparison test for proportions.

[1] All moths touching each trap type were scored as having landed on one of three areas (proportions sum to 1.0). The proportion of moths touching each area that were subsequently captured is summarized in the table under 'Captured'.

The presence or absence of a front flap in either the VI delta or IIB diamond trap did not affect moth capture rates (X^2 = 0.56, df = 1, P = 0.46; X^2 = 0.44, df = 1, P = 0.51, respectively). However, the location of moth contact was significantly different in the VI delta traps with or without flaps (X^2 = 8.96, df = 2, $P < 0.01$) but not with the IIB diamond trap (X^2 = 2.74, df = 2, P = 0.25). Removal of the flap in the VI delta trap increased the proportion of moths that flew directly into the trap versus landing on the front of the trap and walking in.

Lure position did not affect the efficiency of moth capture in VI delta traps (X^2 = 2.19, df = 2, P = 0.24), however it did affect the distribution of moth contact with the trap (X^2 = 10.04, df = 2, $P < 0.01$). When the lure was pinned to the interior top of the trap a majority of moths flew into the trap and first landed on the inside top surface before falling down onto the adhesive. In contrast, a majority of moths first landed on the front flap and walked into traps when the lure was pinned to the center or side of the interior bottom of the trap.

Field trials. Significant differences in moth catch occurred among traps during both field tests (Table 4). Test 1 was conducted in the spring during the first flight of codling moth and few moths were caught in traps. Mean moth catch was significantly lower in the 1CP wing trap versus the other three traps. Test 2 was conducted later in the season and moth catch was > 10-fold higher in this test than during the spring trial due to the high number of moths released into the orchard (> 90% of moths captured were released sterile moths based on the presence of a red internal dye). The IIB diamond and 1CP wing traps with the smallest adhesive-treated surfaces caught significantly fewer moths than the larger VI delta and 1C wing traps in this test. The rate of catch over time leveled off for each trap due to saturation of the adhesive-treated surfaces (Fig. 1). Cumulative catch in both the IIB diamond and 1CP wing traps saturated at about 40 moths per trap (Fig. 1). Cumulative moth catch saturated at a higher level in the VI delta than the 1C wing trap despite having a nearly 30% smaller adhesive-treated surface area (Fig. 1, Table 1).

Table 4.

Comparison of male codling moth catch in several trap types baited with 10 mg codlemone red septa within a sex pheromone-treated apple orchard

	Mean (SE) moth catch per trap	
Trap type	Test 1[a]	Test 2[b]
Pherocon VI Delta	6.3 (0.9)a	93.9 (9.5)b
Pherocon IIB Diamond	6.4 (1.7)a	39.6 (2.2)a
Pherocon 1C Wing	6.6 (1.4)a	77.6 (5.7)b
Pherocon 1CP Wing	3.0 (0.7)b	40.8 (4.6)a
Statistical test	$F_{3,53} = 5.15$ $P < 0.05$	$F_{3,35} = 24.7$ $P < 0.001$

[a] This test was conducted from 17 April to 4 May 1998.

[b] This test was conducted from 20 August to 9 September 1998. The orchard was treated with three releases of 5,000 sterile moths.

DISCUSSION

Codling moth is a direct pest of pome fruit and typically occurs at low densities in commercial orchards. For example, the action thresholds established for moth catch in sex pheromone-baited traps are usually < 5 moths per week (summarized in Riedl *et al.* 1986). Three of the four traps tested in our field study performed similarly in an orchard with a low to moderate population density of codling moth. At higher moth densities, the area of a trap's adhesive-treated surface was an important factor affecting catch. Riedl (1980) found that a density of > 0.2 moths per cm^2 of adhesive-treated surface reduced subsequent codling moth captures in sticky traps. Data from our study was consistent with this estimate (Fig. 1, Table 1). However, other factors, such as visual cues can play a role in the capture efficiency of a trap (Foster et al. 1991). Male *E. postvittana* flying into traps with moths already captured, landed closer to the sex pheromone lure than in clean traps. The influence of previous moth captures within a trap on the orientation and landing behavior of codling moth has not been addressed.

Saturation of sticky traps with moths is a common problem in monitoring tortricid orchard pests that occur at high densities, such as tortricid leafrollers (Brown 1984, Knight 2001). However, our data suggest that saturation is not a factor in any of these trap types when the

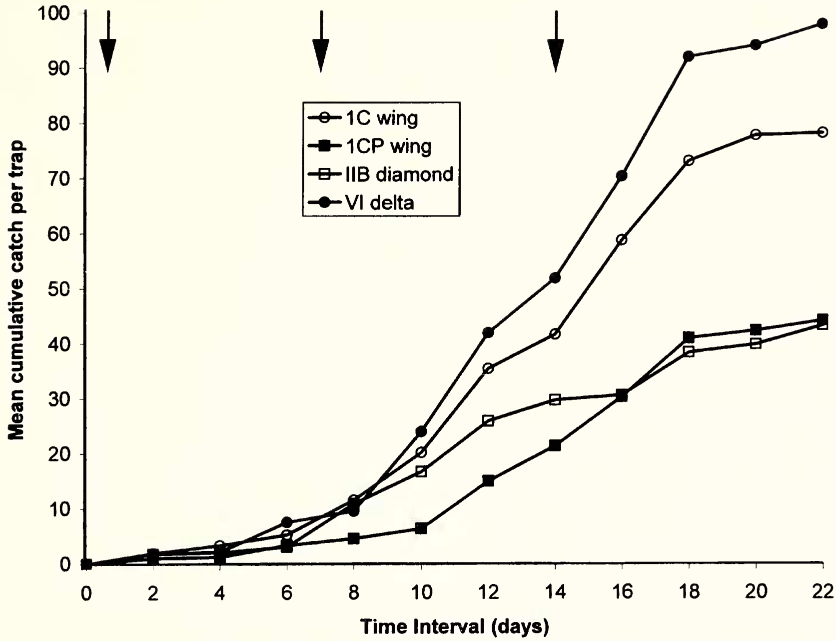

Figure 1. Cumulative catch of codling moth males from 20 August to 9 September 1998 in four trap types placed in a 14-ha apple orchard. Five thousand sterilized codling moths were released in the orchard on 20 August on the first day of the test and again on 27 August and 3 September (release dates indicated by vertical arrows).

cumulative moth catch is < 20 moths. Therefore, current recommendations for codling moth trap maintenance should be adequate, especially in sex pheromone-treated orchards if trap liners are replaced frequently (Riedl *et al.* 1986).

Surprisingly, the Pherocon 1CP wing trap performed poorly in both our flight tunnel and field tests. Previous field trials have reported that the 1CP wing trap was very effective (Charmillot *et al.* 1975) and this trap has been widely used to monitor codling moth in the western United States (Gut and Brunner 1998). However, in our flight tunnel tests the 1CP wing trap was the least effective among the four traps tested in capturing moths after they contacted the trap. In particular, a low proportion of moths landing on the front of the trap were captured. The low efficiency of the 1CP wing trap was apparently due to the absence of adhesive on either side of the center notch on the bottom liner. Qualitative physical evaluations of various 1CP wing traps produced by several manufacturers over the last 15 yr suggest that traps vary tremendously in the deposition of adhesive. Our data suggest that this variability would have a significant impact on the relative performance of these traps.

The presence of a front flap in a trap has been suggested to serve as an effective barrier restricting the ability of moths to exit the trap. Riedl (1986) cited unpublished data that the flap in a diamond-shaped trap increased catch of codling moth. The inclusion of a front barrier in the IOBC cylinder trap significantly increased catch of codling moth (Charmillot *et al.* 1975). Foster and Muggleston (1993) in a flight tunnel test with *Epiphyas postvittana* (Walker) found that the front flap on a delta trap increased the proportion of moths entering the trap that were caught. Interestingly, they also found that the height of the flap influenced the moth's landing position on the adhesive and the catch efficiency of the trap. Higher flaps caused the moths to land further upwind and farther from the trap's exit. Flight tunnel studies with *Ctenopseustis obliquana* (Walker) showed that removing the front flap from a delta trap increased the proportion of moths that entered the trap but also increased the proportion of moths that escaped (Foster *et al.* 1995). The flaps in the diamond and delta traps did not play a significant role in capturing codling moth in our tests. However, we hypothesize that the presence of the flap in the VI delta trap may be responsible for retaining a higher number of moths compared with the IC wing trap in our field tests.

Plume structure and species-specific flight behaviors can influence the effectiveness of trap designs. Clearly, the responses of codling moth we observed to traps placed in clean air in a flight tunnel may or may not be consistent with its' responses to traps placed in an orchard treated with sex pheromone dispensers. Comparative behavioral studies in a flight tunnel of the leafrollers, *Planotortrix octo* (Dugdale) and *E. postvittana* found that the former species was more sensitive to its pheromone plume structure. When delta traps were placed at increasing angles to the wind direction moth orientation and capture of only *P. octo* declined (Foster *et al.* 1991). The wide inter-track reversal distances during anemotactic flight of *C. obliquana* reduced the effectiveness of delta traps (Foster *et al.* 1995). A large proportion of these moths landed on the outside of the trap and lost contact with the plume. Conversely, we found that only a low proportion of codling moths landed on the outside of the VI delta trap; however, a significantly lower proportion of these moths were captured compared with the other trap types. Foster *et al.* (1995) improved the delta trap performance for *C. obliquana* by increasing the pheromone dose of the lure, which decreased the flight tracking angles. They also found that by using a rectangular trap moth capture was improved versus the delta trap with its narrow apex. A rectangular trap design has not been tested for codling moth nor has the influence of lure dosage on male anemotactic flight been reported.

Lure placement within a trap can be an important factor affecting moth capture. The efficiency of the delta trap for *E. postvittana* was increased when the lure was placed at the side of the adhesive-treated bottom surface versus the center or higher in the trap (Foster *et al.* 1991). However, lure placement did not affect the proportion of moths orienting to the trap. In comparison, lure placement in the VI delta trap in our study with codling moth did not affect either capture efficiency or moth orientation. Similarly, McNally and Barnes (1980) reported that there was no difference in the catch of codling moth in a 1C wing trap whether the lure was placed high or low in the trap.

Sex pheromone-baited traps play a critical role in monitoring codling moth in orchards treated with sex pheromone for mating disruption. Trap and lure use have been modified since 1990 when the first pheromone dispensers were registered, to reflect the orchard manager's need to assess moth population density in disrupted-orchards more than to measure the level of disruption in the orchard (Gut and Brunner 1996). Traps are positioned within the orchard and within the canopy to enhance their ability to capture moths, e.g. orchard borders (Knight and Christianson 1999), upper canopy (Knight 1995, Barrett 1995), and distant from pheromone dispensers (Knight *et al.* 1999). Standardization of these factors, as well as trap and lure type, will likely improve monitoring of codling moth. Our data suggest that the currently used delta, diamond, and wing style (1C) traps are equally effective in capturing codling moth at low to moderate moth densities. Proper maintenance of these traps' adhesive surfaces is one factor that can be controlled to improve monitoring of codling moth.

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